GERMINATION, GROWTH, AND WATER RELATIONS OF ASTRAGALUS LENTIGINOSUS VAR. NIGRICALYCIS (FABACEAE)

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ABSTRACT

Astragalus lentiginosus var. *nigricalycis* Jones is a leguminous, drought-evading hemicryptophyte endemic to the San Joaquin Valley of California. Germination in the growth chamber was 0–13 percent by day 20 over a wide range of temperatures (from constant 3°C to alternating 35/20°C) and photoperiods (8–14 hr, 225 W/m^2). In a Temblor Range plot, we obtained 7.5 percent establishment with 115 mm precipitation. Eighteen hr light and 21 ± 4 °C provided optimal conditions for vegetative growth. Davis, CA, field conditions led to flowering by early March. Seed vernalization was not effective in bringing this variety into flowering. Summer dormancy was moisture-dependent. Onset of wilting occurred at −3.8 MPa xylem pressure potential.

Astragalus lentiginosus Dougl. is a complex and variable species, containing many perennial and some annual varieties. Munz (1959) stated that this species is a "group of reticulately interrelated forms, and most of them intergrading freely at the edge of their ranges with vicariant relatives."

A. lentiginosus var. *nigricalycis* Jones is a San Joaquin Valley endemic (Twisselmann, 1967), growing in Mediterranean-type arid and very arid climates (Sankary, 1971) and found as a frequent companion of the Atripleto-Brometum community. It becomes only occasional in the Junipereto-Stipetum community in the Temblor Range, California. Selected strains of var. *nigricalycis* might become an important spring forage legume in arid and very arid zones throughout the world. Its toxicity is debatable. Keeler (1975) in Utah indicated that *Astragalus lentiginosus* is particularly potent in inducing congenital deformities in sheep, but California field observations by Twisselman (pers. comm., 1970) indicate little, if any, toxicity.

In this paper, we examine some factors that affect germination, establishment, growth, reproduction, and water relations of *Astragalus lentiginosus* var. *nigricalycis*. This paper is part of a series of ecological studies on dominant species of comparable Syrian and Californian arid zones (Sankary, 1971; Sankary and Barbour, 1972a, 1972b, 1972c). Plant nomenclature follows Munz (1959).

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Methods

Germination experiments. Seeds of *Astragalus lentiginosus* var. *nigricalycis* were collected in June, 1969, from the Elkhorn Experimental Site, Kern County, in the southern portion of the San Joaquin Valley at approximately 35°10′N. The climate is Mediterranean-type arid with variable precipitation, averaging 145 mm per annum, none falling June through August. The mean maximum/minimum temperatures are estimated as 36/20°C for July and 11/2°C for December (Sankary, 1971).

Seeds were collected in paper bags, then stored in open glass jars at room temperature and exposed to room light. Germination is considered in this work as protrusion of the radicle from the seed coat. When a sand cover was used over sown seeds, all seedlings that appeared above the sand surface were considered established.

To examine the effect of temperature and light on germination, we used growth chambers (Percival PGW-108) for the following treatments: 14 hr light and 12°C, 8 hr light and 23°C, 14 hr light and 30/15°C, and 14 hr light and 35/20°C. We used a cold room for darkness and 3°C, and a germinator for darkness and 30°C. In all experiments we used 7 × 7 × 7 cm plastic pots filled with sterile sand and subirrigated with distilled water. Germinated seeds were counted daily during the first 20 days and a final count was made on the 40th day.

Germination and establishment in the field were followed in a Temblor Range plot located within an exclosure established by the Temblor Range research team of the University of California at 35°10′N, 119°30′W, 200 m elevation. The soil in this plot is a crusty loam of pH 7.2. Soluble salt content is low (0.55–0.63 mmhos/cm), boron is 0.5–1.4 ppm, and $CaCO_3$ is 4.0–4.5 percent. The climate is typically Mediterranean with variable precipitation that averaged 200 mm per annum for 1955–1970. The soil was plowed on 16 December 1969 with a 10 cm cultivator shovel, but the vegetation, mulch, and seeds present were not removed. We employed four replicates, each consisting of a 1 × 1 m plot with four furrows, sown with 400 seeds about 0.5 cm deep and 4 cm apart. Observations on establishment were first made on 29 April 1970.

Growth, reproduction, and dormancy. Growth and reproductive aspects were studied at different thermophotoperiodic regimes at little water stress. The regimes imitated daylength and/or temperatures of all seasons in the natural habitat: 8 hr light and 23°C, 12 hr light and 21 ± 4°C, 14 hr light and 35/20°C, and 18 hr light and 21 ± 4°C. The 8-hr light regime was produced in a growth chamber with light intensity of 290 W/m^2 at plant level (both fluorescent and incandescent bulbs). All other regimes were produced in a greenhouse, with the photoperiod artificially extended (fluorescent and incandescent bulbs, 65 W/m^2 at plant level).

The seedlings for these experiments were raised from seeds germinated in 7 × 7 × 7 cm plastic plots filled with sterilized sand and subirrigated with half-strength Hoagland's solution. As seedlings attained an age of 30–40 days, they were transplanted into subirrigated 18 × 15 cm plastic pots filled with sterilized sand. The pots were watered by distilled water from the top once every 10 days to prevent salt accumulation. Soil solutions never exceeded 1.5 mmhos/cm in electrical conductivity and generally were 1–1.3 mmhos/cm (about −0.05 MPa osmotic potential). Notes on height and phenology were taken at 10 day intervals for 4 months except when specified otherwise. Three plants were used per treatment.

Water relations. The Scholander bomb (Scholander et al., 1965) was used to measure water stress. The data are expressed in megapascals (MPa) of negative water potential (xylem pressure potential). For each measurement, we used a 7–10 cm twig with several leaves. Whenever permitted by the branching pattern and size of the plant, twig sampling was performed systematically from base to top, in order to detect differences in water potential with height. The twig was sealed in a pressure chamber and pressure was applied with compressed nitrogen. The pressure is generally considered equal to the water potential of the leaf cells (Boyer, 1969).

Plants either were subirrigated continuously or were allowed to dry. Four subirrigated plants were used for each thermophotoperiodic regime employed. These plants were 4–5 months old and had been kept for that time in these same regimes. The regimes and the planting and subirrigation methods were identical to those used for studying growth and reproduction.

Additional plants grown in a greenhouse in sandy loam were allowed to dry. Eight 4-month-old plants were divided into four groups, each group composed of two plants in a 15 × 18 cm pot. Initially, for 25 days, all plants were watered at 2 day intervals. The first determination of twig water potential was made at field capacity about 16 hr after the last watering. From then on, no water was given to the plants and moisture determinations were taken periodically (noontime) until wilting occurred. The experiment took place between February and April, with natural photoperiods of 11–12.5 hr.

Results and Discussion

Germination experiments. Germination generally was very poor. By day 20, it ranged from 0 to 13 percent and it was not much higher by day 40. The speed of germination increased with temperature (Table 1). The optimum germination temperature was 35/20°C, which was similar to the pattern for *Astragalus oxyphysus* from California and *A. spinosus* from Syria (Sankary, 1971). Hammouda and Bakr (1969) found that maximum germination of the Egyptian nanopha-

TABLE 1. EFFECT OF TEMPERATURE ON GERMINATION OF *A. lentiginosus* VAR. *nigricalycis*. Average of 3 replicates, 20 seeds each.

Temperature (C°)	Photoperiod (hr at 1800 ft-c)	First day of germination	Germination (%) 10th day	20th day	40th day
3	0	24	—	—	5
12	14	5	3	5	7
23	8	5	7	7	7
30	0	5	3	7	7
30/15	14	5	10	13	13
35/20	14	3	10	13	15

nerophyte *A. sieberi* and the winter annual *A. hamosus* occurred at 30–35°C. This optimum is somewhat anomalous because such temperatures do not occur in nature when there is appreciable soil moisture.

As with many other arid zone species studied by the senior author (Sankary, 1971), sand cover improved germination and aided establishment. Germination was indifferent to photoperiod, however, so the effect of sand may have been improvement of moisture relations around the seed, rather than attrition of light.

In the field plot, *A. lentiginosus* var. *nigricalycis* exhibited an ability to germinate and establish itself with only 115 mm rain, and its rate of establishment was almost equal to that of the Syrian species *Salsola vermiculata* var. *villosa,* seeded at the same time (Sankary and Barbour, 1972a). On 29 April 1970, we recorded 7.5 percent establishment, which is modestly high when compared with 15 percent at optimum temperature in controlled conditions where moisture was not limiting.

The seedlings grew slowly, reaching 2–2.5 cm in April, with 4–5 leaves each. Two naturalized annuals were present in the same plot: *Bromus rubens* and *Erodium cicutarium*. Their growth was also slow, *B. rubens* attaining a height of 5 cm with 1–2 spikelets, and *E. cicutarium* reaching 4 cm with 1–2 fruits per plant. In September, 1978, the plot was revisited. No *Astragalus* survivor was observed, possibly because of competition with *Salsola vermiculata* var. *villosa*. Approximately 5000 *Salsola* plants were present in a 1-ha area about the plot, so it is clear that this species is spreading aggressively and is offering competition that *Astragalus lentiginosus* does not normally encounter in California.

Growth, reproduction, and dormancy. As with 17 other species from the Mediterranean-type arid zones of California and Syria, the 8 hr light and 23°C regime was not effective in bringing *Astragalus* into flowering (Table 2). This regime imitated spring or fall temper-

TABLE 2. EFFECT OF TEMPERATURE AND PHOTOPERIOD ON HEIGHT AND FLOWERING OF *Astragalus lentiginosus* VAR. *nigricalycis*. Average of 3 plants/treatment. FB = formation of visible floral buds; Fr = fruiting. Plants in thermophotoperiod columns 2, 3, and 5 were germinated and grown for 40 days in 14-hour light, 30/15°C before receiving the treatments described.

	Photoperiod (hr) and temperature (C°)				
hr:	8	12	14	14	18
C°:	23	21 ± 4	35/20	35/20	21 ± 4
Day: 10	Height (cm): 1.5	13	14	3.5	10
20	3	15	16	5	13
30	4.5	18	18	7	19
40	6	22	29	10	25
50	9	26	22	14	29
60	12	30	24	20	34
70	15	34 FB	26	23	38
80	20	38	29	25	42
90	25	44 FB	32	28	46
100	31	48	35	30	50
110	—	48 Fr	36	32	55
120	—	48	38	34	60
Flowering (% by day 120)	0	100	0	0	0

atures and short photoperiods. Three plants that had germinated and grown for 100 days in this regime formed visible floral buds within 2 months when transferred into a 14 hr light and 12°C regime. Plants raised from seeds in 14 hr light and 30/15°C for 40 days, then transferred to 12 hr light and 21 ± 4°C (imitating late winter), flowered and fruited by day 90 (Table 2).

At Davis field conditions (4 plants, pot experiment planted on December 5 at age of 1 month), plants formed visible floral buds very early in February, and all were in full bloom by early March. *Astragalus oxyphysus* flowered in a similar pattern, following a relatively long juvenile stage of about 1 year. *Astragalus spinosus* from Syria also flowered in nature by February. Apparently, all these species are short-day plants (Sankary 1971, 1977).

Plants raised from seeds in 14 hr light and 30/15°C for 40 days, then transferred to 14 hr light and 35/20°C (imitating early summer) grew well and did not enter summer dormancy. This regime did not promote flower induction, whether the seeds were vernalized or not, although the vegetative growth was good (Table 2). Under Davis field conditions with maximum daily temperatures above 40°C, *Astragalus* continued growing all summer, as long as moisture was available. This indicates that summer dormancy is controlled by moisture, not by temperature.

Plants raised from seeds in 14 hr light and 30/15°C for 40 days, then

TABLE 3. RELATIONSHIP BETWEEN TWIG WATER CONTENT AND WATER POTENTIAL WITH PROGRESSIVE DECREASE IN SOIL MOISTURE. Average of two readings from two plants.

Plant water content (% dry weight)	Twig water potential (MPa)	Average plant condition
78.2	−1.1	All leaves turgid, soil at field capacity
75.8	−1.6	
71.2	−1.9	
62.0	−2.8	Lower leaves permanently wilted
60.0	−3.8	95% of leaves dried, only two youngest leaves still unwilted (all leaves recovered upon rewatering)

transferred to 18 hr light and 21 ± 4°C (long photoperiod, spring or fall temperatures) grew optimally and neither flowered nor entered summer dormancy (Table 2).

A final group of plants was exposed to a gradual change of temperature, imitating a change from winter to early summer, with a constant photoperiod of 14 hr. Eight seedlings were grown for their first 2 mo at 12°C. Shoot growth was slow, height reaching only 2 cm and only two leaves per plant developing. Root growth was 10–15 cm, however. By the end of the second month, seedlings reached a height of 5 cm and developed six leaves. Then three plants were selected and temperatures raised to 30/15°C for 2 months, then raised again to 35/20°C for one additional month.

This sequential change did not induce flowering or dormancy, but did result in rapid shoot growth: 15 cm height the third month, 28 cm the fourth, and 36 cm the fifth.

Water relations and drought endurance. Plants continuously subirrigated showed an average predawn water potential of −0.3 MPa and an average noon water potential of −1.0 MPa, with relatively little difference among the four thermophotoperiodic regimes used. This average was about 50–60 percent less negative than those of such summer-active shrubs as *Atriplex polycarpa, A. lentiformis, A. lencoclada, Salsola vermiculata,* and *Haloxylon articulatum* (Sankary, 1971; Sankary and Barbour, 1972a, 1972b, 1972c).

When those plants were allowed to dry, twig water content and water potential dropped gradually until there was a sharp decrease as the soil approached the permanent wilting point (Table 3). On 29 April 1970 (a dry year), *Astragalus* plants in the arid zone of California were dry, while adjacent *Atriplex polycarpa* plants were still actively growing. Field measurements showed that *A. polycarpa* endured very low twig water potentials of −6.9 MPa (Sankary and Barbour, 1972a), while Table 3 shows that *Astragalus* did not tolerate noon values below −3.8 MPa. In relative terms, *Astragalus* is a drought evader.

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